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WIDEBAND COOPERATIVE SPECTRUM SENSING AND SIGNAL DETECTION f6 F-9: B; 'G@89GL

JULY 2013

INTERIM TECHNICAL REPORT

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14. ABSTRACT These presentation slides are provided as an interim report of the in-house project titled "Wideband Cooperative Spectrum Sensing". The objective of this effort is to develop wideband cooperative spectrum sensing and signal detection techniques. Two sensing steps are used to detect and exploit the signals of interest: Coarse sensing to determine the presence or absence of signals within scanned frequency bands; and fine sensing by exploiting the features of signals.					
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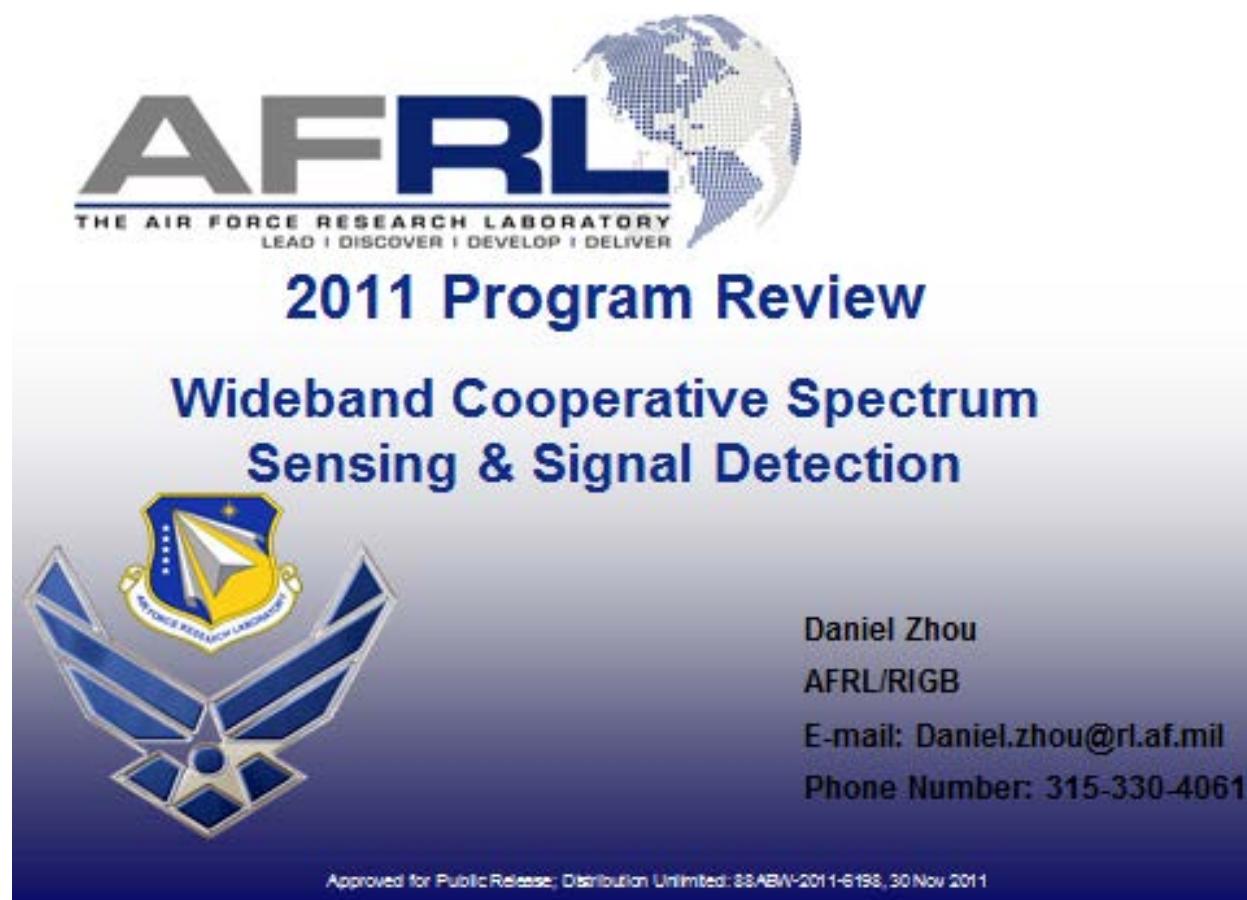
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1 Abstract

This presentation slides are provided as an interim report of the in-house project titled “Wideband Cooperative Spectrum Sensing”. The objective of this effort is to develop wideband cooperative spectrum sensing and signal detection techniques. (Slide 3) Two steps sensing are used to detect and exploit the signals of interest: Coarse sensing to determine the presence or absence of signals within scanned frequency bands; and fine sensing by exploiting the features of signals. (Slide 5)

2 Presentation Slides

The presentation slides provided in the next pages summarize the work performed in this in-house project during the FY-12.



The slide features the AFRL logo at the top left, which includes the text "AFRL", "THE AIR FORCE RESEARCH LABORATORY", and "LEAD | DISCOVER | DEVELOP | DELIVER" along with a globe graphic. To the right of the logo, the text "2011 Program Review" is displayed in a large, bold, blue font. Below this, the title "Wideband Cooperative Spectrum Sensing & Signal Detection" is centered in a large, bold, blue font. To the left of the title is the Air Force Research Laboratory (AFRL) shield logo, which is blue with a yellow and white emblem. On the right side of the slide, the contact information for Daniel Zhou is listed: "Daniel Zhou", "AFRL/RIGB", "E-mail: Daniel.zhou@rl.af.mil", and "Phone Number: 315-330-4061". At the bottom of the slide, a blue footer bar contains the text "Approved for Public Release; Distribution Unlimited: 88ABW-2011-6198, 30 Nov 2011".

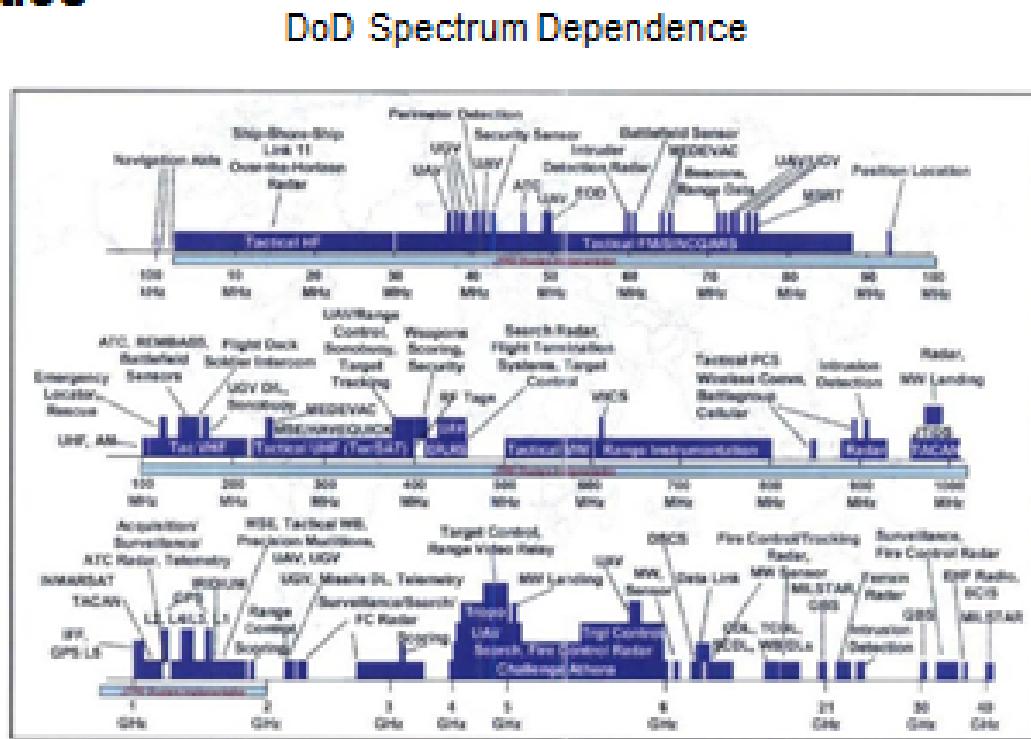


DoD Spectrum Dependence



DoD use spectrum to provide capabilities

- Communication
- Telemetry
- Surveillance
- Radio location
- Radio navigation
- RDT&E



Source: Ralf P.



Program Objective



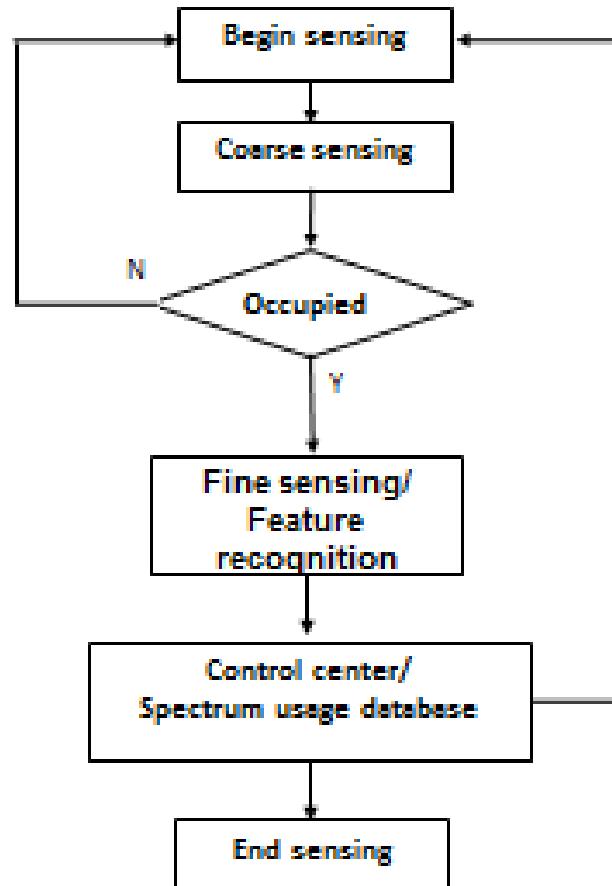
- To achieve effective spectral awareness
 - Sensing method capable of making cooperative decisions over multiple frequency bands is essential
 - Many conventional spectrum sensing methods
 - Either single-channel or non-cooperative signal detection
 - Vulnerable to noise uncertainty, fading, and shadowing
- Objective: develop wideband cooperative spectrum sensing and signal detection techniques
 - Spatial diversity: multi-sensors joint decision
 - Spectral diversity: multi-channel detection
 - Effective spectral awareness



Approach



- Cooperative sensing: single sensor to multiple sensors
- Wideband sensing: single-channel to multi-channel
- Two steps sensing to detect and exploit the signals of interest (SOI)
 - Coarse sensing (signal detection): determine the presence or absence of signals within scanned frequency bands
 - Fine sensing (feature recognition): exploiting the features of signals





Coarse Sensing/Signal Detection



- Objective: quickly & reliably determine the existence of signals in multiple frequency bands by joint detection
- Challenge:
 - No prior information about the signals, blind/semi-blind detection approaches
 - Speed: low computational complexity to achieve quick sensing (low complexity leads to less accurate sensing result)
 - Accuracy: multi-sensors/antennas cooperative sensing to improve the performance
- Two main tasks:
 - Develop a wideband blind/semi-blind sensing method that has the right balance between speed and accuracy
 - Find optimal cooperation strategy to combine sensing results from multiple sensors



Fine Sensing/Feature Recognition



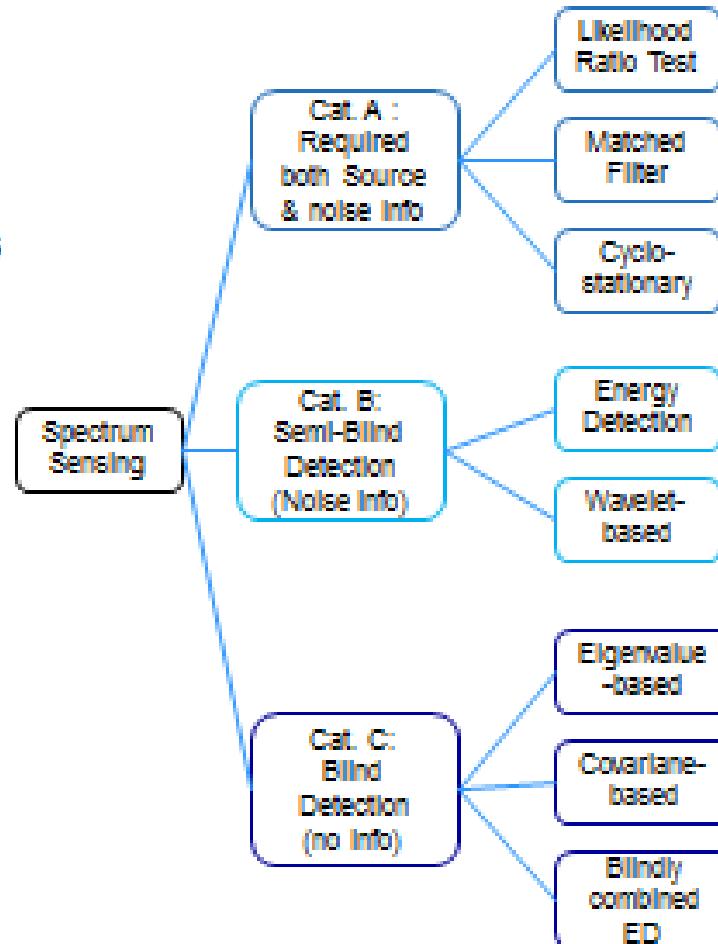
- **Objective:** exploit & estimate the features (i.e. bandwidth, center frequency, modulation type, etc.) of a signal
 - Fine sensing initiate only when signals been detected in the coarse sensing
 - Some information regarding the noise distribution or signal distribution may already been obtained
 - Known pieces of information can be passed on to fine sensing to assist with features recognition
 - Methods require signal and/or noise information can be used



Sensing Methods



- Spectrum sensing & signal detection is not new
- Cognitive Radio further stimulates its development
- Each method has different requirements for implementation
- Complexity and accuracy of sensing methods is increasing as the information required for detection increasing





Cooperative Detection



- Constraint of many conventional detection methods
 - Non-cooperative signal detection in single frequency band
 - Sensing reliability degraded due to noise and fading
- Information from multiple sensors can be combined to obtain more accurate decision

Cooperative Sensing		
Distributed	Centralized	
share information among each other but make own decisions	Data feed: each node send raw data, central unit make decision	Decision feed: process data, send only the decision to central unit



Cooperation Strategies



- **Each cooperation strategy has its own decision rule for signal detection**

Strategies	Decision Rule for Detection
Voting	# of votes for detection > # of votes for no detection
OR	Out of N individual decision, any one detected signal
AND	All sensing nodes have to detect signal
Linear combination	Normalized weight assigned to local decision according to their SNR, global decision reached by combining weighted local decision



Mathematical Model



- The problem of detection of the signal can be modeled as a binary hypothesis testing problem:

$$\mathcal{H}_0 : y_i(n) = w_i(n)$$

$$\mathcal{H}_1 : y_i(n) = s_i(n) + w_i(n)$$

- The performance of the detection algorithm can be summarized with 2 probabilities: probability of detection and probability of false alarm:

$$p_f = \Pr (T > \gamma | \mathcal{H}_0)$$

$$p_d = \Pr (T > \gamma | \mathcal{H}_1)$$

Small P_f results in higher spectrum efficiency

Large P_d value lead to better chance of detecting signal

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Linear Cooperative Sensing



- **Individual sensor**
 - Calculates a summary statistic over an interval of N samples
 - Then statistic is sent to fusion center
- **Fusion center**
 - Assigns a weight to each sensor based on the summary statistic received, then combine them linearly
 - The weight for a particular sensor represents its contribution to the global decision
 - Large weight assigned to those sensors have high-SNR; small weight for sensors with low-SNR



MATLAB Simulation



Parameters: Primary user's signal $s(k)=1$; # of samples: $N=20$;
fixed channel noise variance of 0.5; # of cooperative sensors: $M=1, 3$, and 6

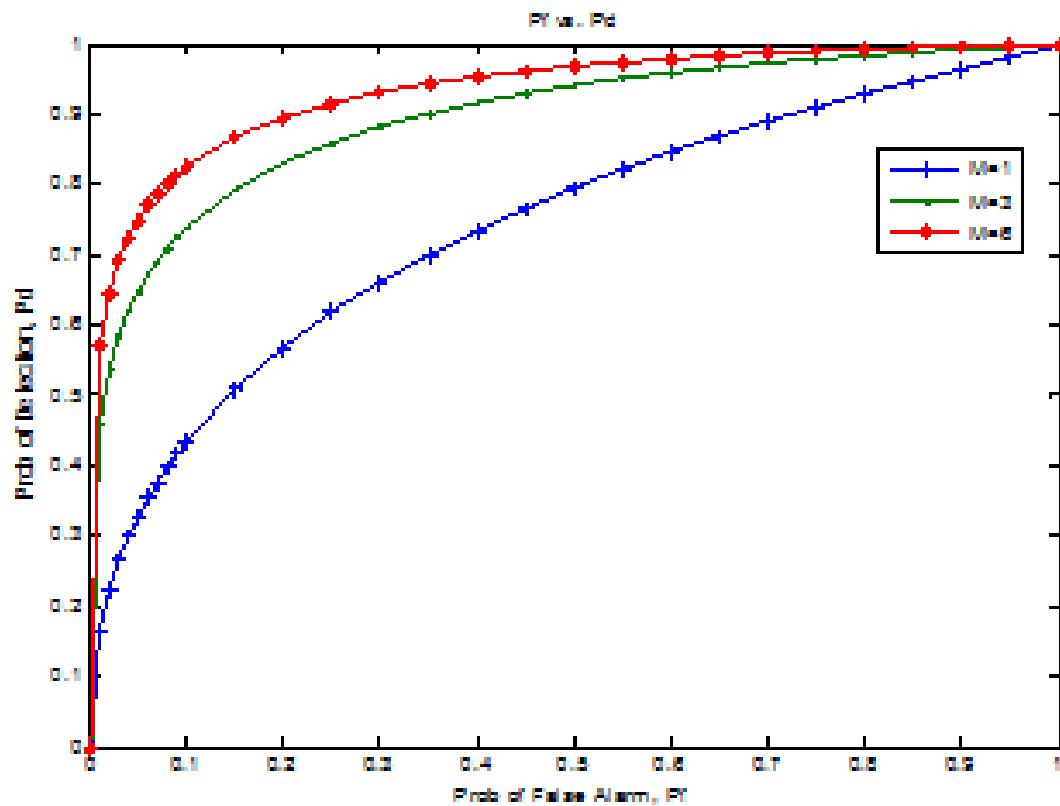
	M=1	M=3	M=6
SNR (dB)	8.3	{10.4, 9.3, 2.6}	{7.2, 5.1, 10.8, -1.2, 3.6, 9.7}
Sensing noise Variance	1.9	{0.7, 1.0, 0.9}	{0.9, 1.3, 1.0, 2.0, 1.8, 1.2}

Result of optimal weights and P_d values for a given P_f value

	M=1	M=3	M=6
Weight Vector	1	{0.8348 0.5165 0.1909}	{0.4713; 0.2328 0.6758; 0.0438 0.1285; 0.4986}
P_d (given $P_f=0.1$)	0.4342	0.7408	0.8265
P_d (given $P_f=0.6$)	0.8463	0.9599	0.9803



Simulation Plot



Probability of detection vs. Probability of false alarm

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Wavelet-based Sensing



Goal:

- **Investigate the potential of wavelet transform for wideband cooperative signal detection**

Motivation:

- **Extensive research on wavelet analysis for images and time series**
- **Only limited research has applied wavelet approach to spectral detection**
 - Work by Z. Tian & G.B. Giannakis: Edge detection [2]
 - Work by Y. Hur, & J. Park: Multi Resolution [3]
 - Non-cooperative detection

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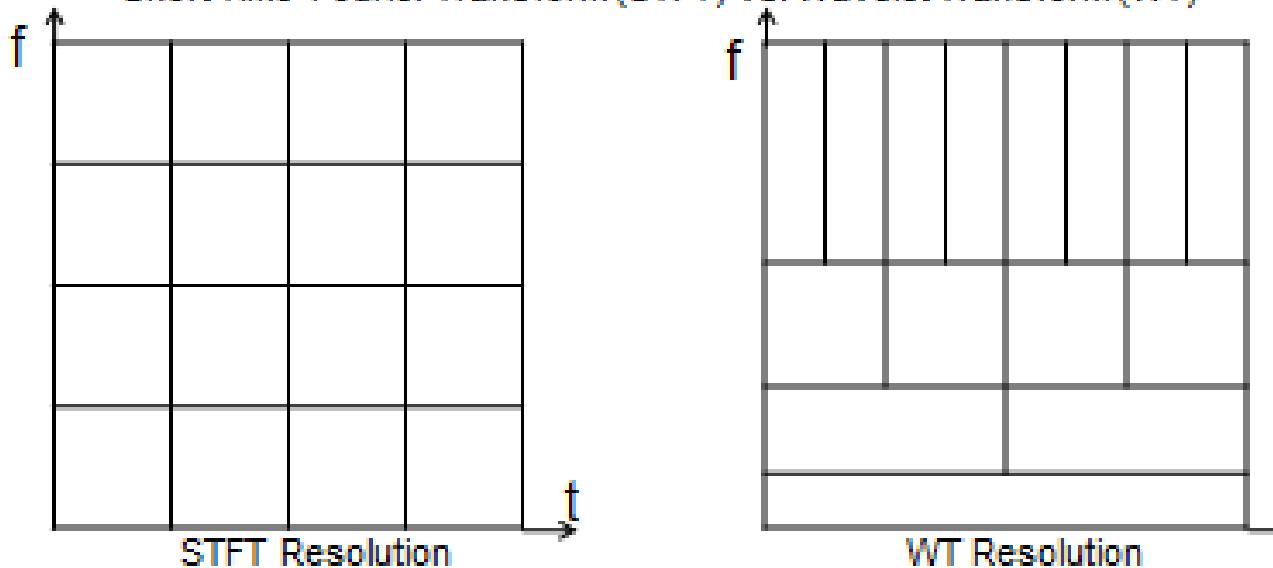
Time-Frequency Analysis



Fourier Transform vs. Wavelet Transform

	Fourier Transform	Wavelet Transform
Processing Signal Type	Stationary	Non-stationary
Provided Information	Frequency	Both time and frequency

Short Time Fourier Transform (STFT) vs. Wavelet Transform (WT)





Wavelet Transform



- **Continuous Wavelet Transform (CWT)**

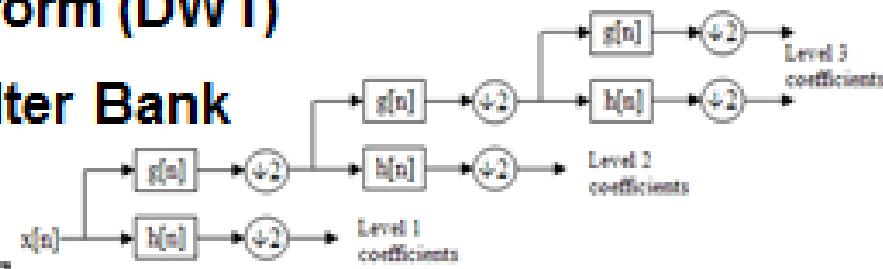
- The mother wavelet function $\psi(t)$

- The scale factor a

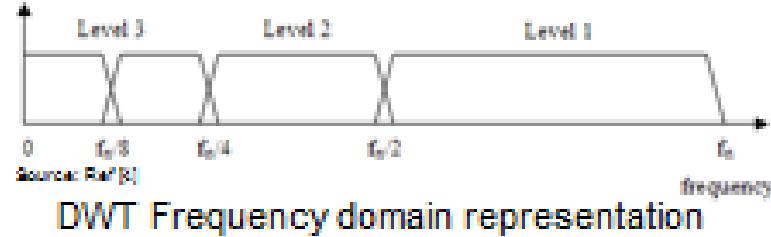
$$X_w(a, b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \psi^* \left(\frac{t-b}{a} \right) dt$$

- **Discrete Wavelet Transform (DWT)**

- Decomposition by Filter Bank



Level	Frequencies	# of Coefficients
3	0 to $f_n / 8$	$n/8$
	$f_n / 8$ to $f_n / 4$	$n/8$
2	$f_n / 4$ to $f_n / 2$	$n/4$
1	$f_n / 2$ to f_n	$n/2$



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Next Step

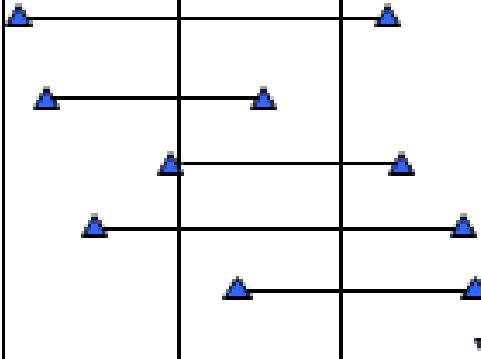


- **Linear Cooperative Sensing**
 - Extend to wideband detection
- **Wavelet-based Sensing**
 - Continue working on the simulation code to investigate the effectiveness for wideband sensing
 - Feasibility for cooperative sensing
- **Investigating other blind detection methods**
 - Eigenvalue-based
 - Sub-space analysis



Program Schedule



	FY11	FY12	FY13
Project Phases <ul style="list-style-type: none">• Research• Algorithm for coarse sensing• Algorithm for fine sensing• Software Development• Software Test• Final Technical Report			

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3 References

- [1] Department of Defense Net-Centric Spectrum Management Strategy, Assistant Secretary of Defense (Networks and Information Integration) Department of Defense Chief Information Officer, 3 August 2006.
- [2] Z. Tian and G. B. Giannakis, “A wavelet approach to wideband spectrum sensing for cognitive radios”, in Proc. *1st Int. Conf. Cogn. Radio Oriented Wireless Netw. Commun. (CROWNCOM)*, Greece, Jun. 8–10, 2006, pp. 1–5.
- [3] Y. Hur, J. Park, W. Woo, K. Lim, C.-H. Lee, H. S. Kim, and J. Laskar, “A wideband analog multi-resolution spectrum sensing (MRSS) technique for cognitive radio (CR) systems,” in Proc. *IEEE Int. Symp. Circuits Systems (ISCAS)*, Island of Kos, Greece, May 2006, pp. 4090–4093.
- [4] http://en.wikipedia.org/wiki/Discrete_wavelet_transform

List of Acronyms

SOI	Signals of Interest
SNR	Signal to Noise Ratio
Pd	Probability of Detection
Pf	Probability of False Alarm
CWT	Continuous Wavelet Transform
DWT	Discrete Wavelet Transform